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A NEW BOOST REGULATOR BASED INDUCTION MOTOR DRIVE

Santosh D. Gadekar[1], A. A. Bhole[2]

[1,2]Department of Electrical Engineering,
Government College of Engineering, Aurangabad, India

ABSTRACT

Simplicity and ruggedness of Induction motor makes it suitable for many applications. There is wide range of machine easily available. The control and estimation of ac drives is more complex than those of dc drives. Almost all the types of ac drive require variable frequency for speed control. The timely varying inductances make this drive more complex for close loop control. So there is a need of harmonically filtered converter power supplies for the better operation of these drives. In the PWM Inverter fed Induction motor drives the current drawn by power semi converter devices from the line is distorted in nature.Distorted nature of current gives rise to high value of Total Harmonic Distortion (THD) and low Power Factor (PF). So there is a continuous need for power factor improvement and reduction of line current harmonics. This paper aims to study the single switch boost converter approach to minimize the Total Harmonic Distortion for an Inverter drive.

Keywords: Boost Converter, Induction motor, Power Factor, PWM Inverter, Total Harmonic Distortion (THD)

1. INTRODUCTION

The various nonlinear loads are power converters, arcing devices, magnetic devices, and rotating machines. These nonlinear loads change the sinusoidal nature of the ac power current, resulting in the flow of harmonic currents in the ac power system.The harmonic current introduced in the ac power system can cause interference with communication circuits, harmonic heating. In case of rotating machines the harmonic current can cause higher audible noise emission, resultant rotor heating, pulsating or reduced torque, cogging and crawling[1].The static power converters are the largest nonlinear loads used in the industry. Almost all types of scalar control and vector control in Induction motor drive uses static power converters. Here ac to dc conversion is achieved by using 1-ϕ or 3-ϕ diode bridge rectifier. The diode bridge rectifier's source current is affected by a large Total harmonic distortion (THD) leads to large ripple and low power factor.So it is very essential to bring up the power factor to near unity. In this paper a three phase rectifier chopper for PWM Inverter fed

Induction motor drive is discussed. The starting current in the Induction motor is about the six-seven times the rated current. This very high current cause the voltage dip in the system and eventually it creates disturbances to the normal operation of other system load [2]. So this unique drive is capable of providing reduced voltage during the start and also the drive functions very good for variable load torque operation. To reduce the Total Harmonic Distortion and to improve the input power factor, it is required to perform the three functions: input current shaping, energy storage, and output voltage regulation.

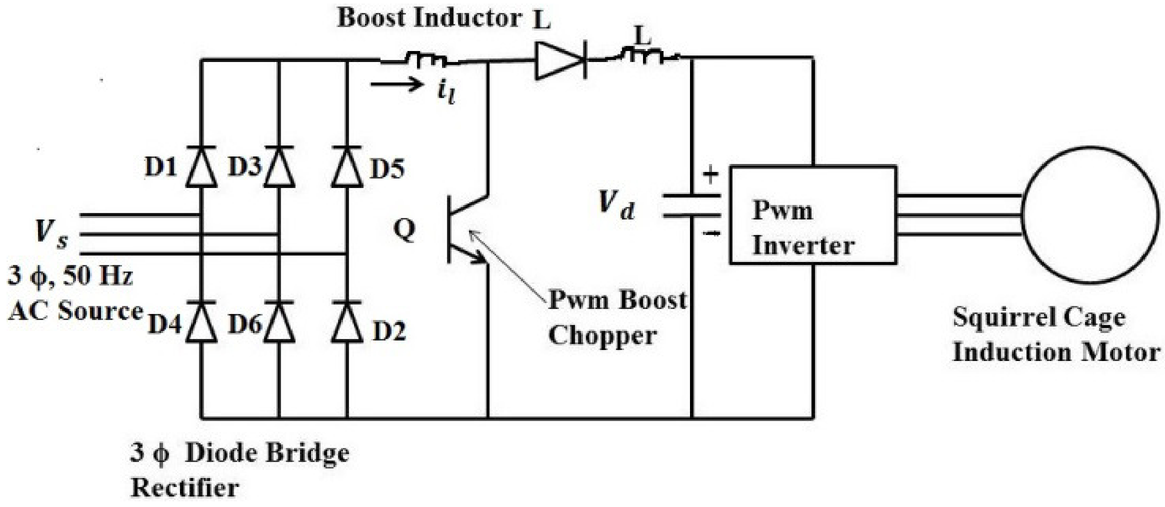

Fig. 1 Three phase diode bridge rectifier with single switch boost converter Induction motor drive

2. PRINCIPLE OF OPERATION

In this paper a single switch boost converter is analyzed with a 3-ϕdiode bridge rectifier for the purpose of power factor correction. As this 3-ϕ diode bridge rectifier has very good rectifier efficiency, better transformer utilization factor with a very less ripple voltage as compare to 1-ϕ diode bridge rectifier [3].The circuit diagram shown in figure 1 consists of a 3-ϕ diode bridge rectifier, a boost inductor, output filter capacitor and inductor. Here boost inductor is used as an energy storage element which has the tendency to resist the changes in current. The boost chopper performs two functions: 1.It minimizes the total harmonic distortion of the source current, and 2.It regulates the capacitor voltageV_d, which should always be higher than the peak line voltage [4].When the IGBT, Q is turned on, a symmetrical short circuit occurs at the rectifier input, the phase current build up linearly, independently of each other, and the magnitude is proportional to the respective phase voltage amplitude. This means that the positive phase voltage cause positive currents through the upper diodes, which return as negative currents through the lower diodes, that are caused by the negative voltages. The current increment $+\Delta i_l$ is as given in [5].

$$+\Delta i_l = \frac{V_s}{L} t_{on} \tag{1}$$

Where $+\Delta i_l$ = change in inductor current during the on interval (t_{on}) of Q.When the IGBT Q turns off, the phase currents flow to the output capacitor until they fall to zero linearly. The expression for the current decrement is as given in [5].

$$-\Delta i_l = \frac{(V_d - V_s)}{L} t_{off} \tag{2}$$

Where t_{off} = off time of the chopper. The slope of the current i_l will vary depending on the voltage impressed across the boost inductance L. Since $|+\Delta i_l| = |-\Delta i_l|$, the switching frequency of the chopper is given as

$$f_{sw} = \frac{1}{(t_{on}+t_{off})} = \frac{V_s(V_d - V_s)}{\Delta i_l L V_d} \tag{3}$$

Where Δi_l = peak-to-peak ripple current. From equation (1) and (2)

$$V_d = V_s\left(\frac{T}{T - t_{on}}\right) \tag{4}$$

$$V_d = V_s\left(\frac{1}{1-D}\right) \tag{5}$$

From equation (5) it is seen that the output voltage is always higher than input voltage. The output voltage is controlled by varying duty cycle (D) with variation of dc reference voltage.

3. TOTAL HARMONIC DISTORTION MINIMIZTION METHODS

The Total Harmonic Distortion is a measure of the harmonic content present in the input source current. With the increase in the value of Total Harmonic Distortion the harmonic content in the source current increases and hence increases the distortion in the source current. The Total Harmonic Distortion is equal to the rms value of all the harmonics divided by the rms value of fundamental component of the input current. The Total Harmonic Distortion of input supply current is

$$THD = \sqrt{\left(\left(\frac{I_s}{I_{s1}}\right)^2 - 1\right)} \tag{6}$$

WhereI_s = rms value of source current and I_{s1} = rms value of fundamental component of source current.

If we take Input Displacement Factor equals to unity then the equation (6) becomes

$$THD = \sqrt{\left(\left(\frac{1}{PF}\right)^2 - 1\right)} \tag{7}$$

From equation (7) it is clear that if we go on decreasing the Total Harmonic Distortion, the Input Power Factor increases. There are basically two steps involved in the minimization of Total Harmonic Distortion.

3.1Input Current Shaping

The basic need for Input current shaping is to have better efficiency and less noise in the ac power system. If source current has a harmonic content of any order that is not present in the respective phase voltage, in such a case there is a power loss. That leads to the drop in the rectifier efficiency. Also the internal switching of power converter and harmonics in the source current creates noise [6]. There are two ways of Input Current Shaping, Passive and Active current shaping. Here the Passive Inductor Filter doesn't require any switches but there is limitation on highest power factor that can achieve is 0.9. So to achieve almost unity power factor we can employ Input Resonant Filter, which are basically a capacitor and inductor connected in series. The Active current shaping uses a switch and an inductor in series with the rectified line. As long as the current flows through

this inductor and the switch, the voltage across the inductor builds up. Thus by varying the turn on time of this switch we can shape the source current.

3.2Energy Storage

It is always good to consider a little extra energy than the minimum energy required to balance the output voltage. Though one could think it as the extra cost and weight but it would be more reliable and cost worthy if the circumstances requires needing of an extra power in the event of sudden load changes. The input ripple current decides the value of boost inductor. We can make a small ripple current to flow by increasing the value of boost inductance. The equation (8) shows the relation between the boost inductance and the input ripple current as given in [7].

$$L = \frac{V_S D}{(f_S \Delta I)} \tag{8}$$

Where D = duty cycle of IGBT, f_s = switching frequency and ΔI = input ripple current.

4. OUTPUT L-C FILTER DESIGN

An L-C filter consists of inductor L in series with the load and capacitor C across the load. The ripple factor in L-C filter has lower value than obtained by either L-filter or C-filter for the same values of L and C. The value of filter capacitor C can be obtained as given in [8].

$$C = \frac{10}{2\omega\sqrt{R^2+(2\omega L_L)^2}} \tag{9}$$

Where ω = angular frequency, R = load resistance and L_L = load inductance.
Voltage Ripple Factor is considered as 10%. The value of filter inductor L can be obtained as given in [8].

$$VRF = \frac{\sqrt{2}}{3}\left[\frac{1}{(2\omega)^2 LC-1}\right] \tag{10}$$

5. PERFORMANCE ANALYSIS

The analysis has been done using the Matlab Simulink Software. The compltete drive system parameters are represented in the table 1.

Table 1: Specification of induction motor drive

Item	Value
Rectifier rms input voltage (V)	145
Boost inductor (H)	0.03
Output L filter (H)	0.002609796
Output C filter (F)	0.01597
Induction motor (kW)	2.2
Rated Voltage (V)	400
Pole	4

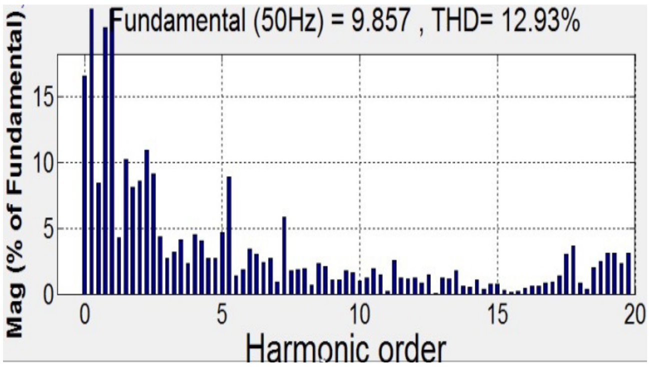

Fig. 2 Three phase diode bridge rectifier source current harmonic content

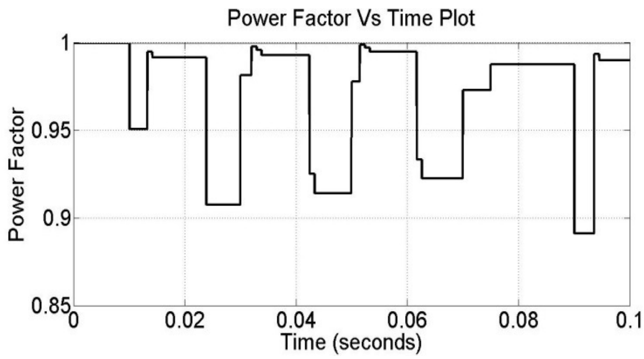

Fig. 3 Three phase diode bridge rectifier source side power factor

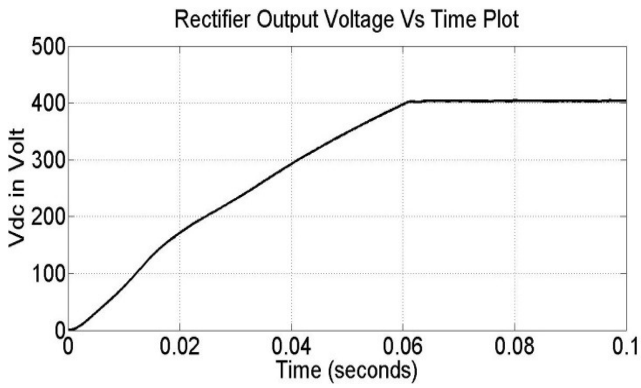

Fig. 4 Three phase diode bridge rectifier output voltage

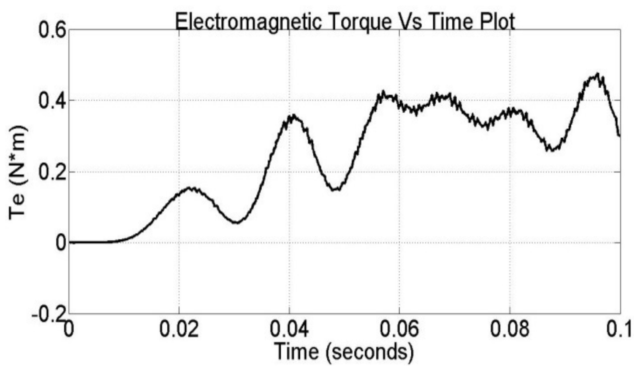

Fig. 5 Three phase Induction motor Electromagnetic torque

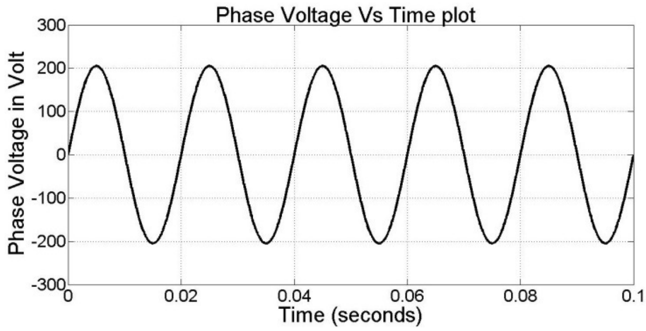

Fig. 6 Three phase diode bridge converter input phase voltage

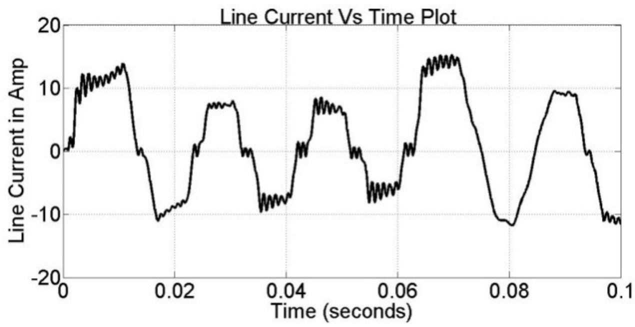

Fig. 7 Three phase diode bridge rectifier source current

Figure 2 and Figure 3 shows the harmonic content in the source current and source current power factor. It is found in the Matlab Simulink FFT analysis that there is 3.61% of third harmonic current, 4.39% of fifth harmonic current,2.03% of seventh harmonic current, 0.45% of eleventh harmonic current and 1.35% of thirteenth harmonic current and then onwards it goes on decreasing. Here we can easily observe that the source current has odd harmonic of the fifth order has a dominant value. All other odd harmonics have much lesser value. The figure 2 shows the magnitude in percentage of fundamental for dc component and for harmonic order from fundamental. It is very good observable that the source power factor doesn't fall below 0.89 and fluctuation observed are because of controller action which tries to get the output voltage equal to reference voltage. Once the system becomes stable then onwards source power will no longer fluctuating. Figure 4 shows rectifier output voltage, as it takes 0.06 seconds to achieve the reference voltage. This time is very much adjustable using the boost inductor value. Then the figure 5 shows change in Electromagnetic torque with respect to time. The Electromagnetic torque is increasing in the positive direction and the fluctuations are only in the upward region, which specify that the motor can easily get the torque required by the load. Figure 6 and 7 shows the rectifier input voltage and line current. Though there are certain notches present in the rectifier source current but this current waveform is much similar to pure sinusoidal voltage waveform. We can remove these notches completely using multiple switch network buck-boosts converter. This new technology is in the developing stage, where there is required to control the output voltage separately.

6. CONCLUSION

In case of nonlinear loads it is very important to control the shape of the source current waveform. As shape directly reflects the harmonic contents in the ac source power system. This drive can be used in future to remove the problems associated with odd harmonic of the order 5^{th},

7th, 11th and 13th. If we precisely select inverter and its motor side filter, we can minimize the crawling and cogging. By controlling the duty cycle of IGBT switch, we can operate this drive for variable voltage fixed frequency application.

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